

## Plutonium

**What Is It?** Plutonium in its pure form is a very heavy, silver-colored, radioactive metal about twice as dense as lead. Essentially all the plutonium on earth has been created within the past six decades by human activities involving fissionable materials. Several plutonium isotopes exist, all of which are radioactive. (Isotopes are different forms of an element that have the same number of protons in the nucleus but a different number of neutrons.)

<b>Symbol:</b>	<b>Pu</b>
<b>Atomic Number:</b> (protons in nucleus)	<b>94</b>
<b>Atomic Weight:</b> (not naturally occurring)	<b>-</b>

The main isotopes at Department of Energy (DOE) environmental management sites are plutonium-238, plutonium-239, plutonium-240, and plutonium-241. Except for plutonium-241, these isotopes decay by emitting an alpha particle.

Plutonium-241 decays by emitting a low-energy beta particle to americium-241, an alpha-emitting radionuclide with a half-life of 430 years that is much more radiotoxic than its parent. The maximum activity of americium-241 is about 3% of the initial activity of plutonium-241 and occurs 73 years later. A very small percentage of the decays of plutonium-238, plutonium-240, and plutonium-242 are by spontaneous fission (SF); about 0.1% of plutonium-244 decays are by SF. Plutonium-242 and plutonium-244 are generally present in relatively minute activity concentrations.

Radioactive Properties of Key Plutonium Isotopes						
Isotope	Half-Life (yr)	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
				Alpha ( $\alpha$ )	Beta ( $\beta$ )	Gamma ( $\gamma$ )
<b>Pu-238</b>	88	17	$\alpha$	5.5	0.011	0.0018
<b>Pu-239</b>	24,000	0.063	$\alpha$	5.1	0.0067	<
<b>Pu-240</b>	6,500	0.23	$\alpha$	5.2	0.011	0.0017
<b>Pu-241</b>	14	100	$\beta$	<	0.0052	<
<b>Pu-242</b>	380,000	0.0040	$\alpha$	4.9	0.0087	0.0014
<b>Pu-244</b>	83,000,000	0.000018	$\alpha$	4.6	0.0071	0.0012

*Ci = curie, g = gram, and MeV = million electron volts; "<" means the radiation energy is less than 0.001 MeV. (See the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for an explanation of terms and interpretation of radiation energies.) Values are given to two significant figures.*

**Where Does It Come From?** Plutonium was first made in large quantities by American scientists in the 1940s as part of the Manhattan Project to create the atomic bomb, and this production continued through the Cold War. Plutonium is formed when the nucleus of a uranium atom captures one or more neutrons, changing the atomic structure and creating a new element. This process occurs in nuclear reactors and mainly involves transforming uranium-238 into plutonium. (Extremely small quantities of plutonium were created naturally in sustained underground nuclear reactions estimated to have occurred about 1.9 billion years ago in Gabon, Africa. This phenomenon occurred because concentrations of uranium-235 were much higher at that time. The current uranium-235 concentration, about 0.72%, will not sustain such natural reactions.)

**How Is It Used?** The nuclear properties of plutonium-239, as well as our ability to produce large amounts of nearly pure plutonium-239, led to its use in nuclear weapons and nuclear power. The fissioning of uranium-235 in the reactor of a nuclear power plant produces two to three neutrons, and these neutrons can be absorbed by uranium-238 to produce plutonium-239 and other isotopes. Plutonium-239 can also absorb neutrons and fission along with the uranium-235. Plutonium fissions provide about one-third of the total energy produced in a typical commercial nuclear power plant. The use of plutonium in power plants occurs without it ever being removed from the nuclear reactor fuel, i.e., it is fissioned in the same fuel rods in which it is produced. Another isotope, plutonium-238, is used as a heat source in radiothermal generators to produce electricity for unmanned spacecraft and interplanetary probes.

The United States recovered or acquired about 110,000 kilograms (kg) of plutonium between 1944 and 1994, and about 100,000 kg remains in inventory. Of this amount, over 80% is in the form of weapons-grade plutonium, primarily plutonium-239. Plutonium was generated in production reactors at DOE's Hanford and Savannah River sites, and weapons components were produced at the Rocky Flats facility. Surplus plutonium is currently stored at the Pantex Plant and other sites.

**What's in the Environment?** Atmospheric testing of nuclear weapons, which ceased worldwide by 1980, generated most environmental plutonium. About 10,000 kg were released to the atmosphere during these tests. Average



plutonium levels in surface soil from fallout range from about 0.01 to 0.1 picocurie per gram (pCi/g). Accidents and other releases from weapons production facilities have caused greater localized contamination. The most common form in the environment is plutonium oxide. Plutonium is typically very insoluble, with the oxide being less soluble in water than ordinary sand (quartz). It adheres tightly to soil particles and tends to remain in the top few centimeters of soil as the oxide. In aquatic systems, plutonium tends to settle out and adhere strongly to sediments, again remaining in the upper layers. Typically one part of plutonium will remain in solution for every 2,000 parts in sediment or soil. A small fraction of plutonium in soil can become soluble through chemical or biological processes, depending on its chemical form. While plutonium can bioconcentrate in aquatic organisms, data have not indicated that it biomagnifies in aquatic or terrestrial food chains. At Hanford, the highest concentrations of plutonium are in areas that contain waste from the processing of irradiated fuel, such as the tanks in the central portion of the site.

**What Happens to It in the Body?** When plutonium is inhaled, a significant fraction can move from the lungs through the blood to other organs, depending on the solubility of the compound. Little plutonium (about 0.05%) is absorbed from the gastrointestinal tract after ingestion, and little is absorbed through the skin following dermal contact. After leaving the intestine or lung, about 10% clears the body. The rest of what enters the bloodstream deposits about equally in the liver and skeleton where it remains for long periods of time, with biological retention half-lives of about 20 and 50 years, respectively, per simplified models that do not reflect intermediate redistribution. The amount deposited in the liver and skeleton depends on the age of the individual, with fractional uptake in the liver increasing with age. Plutonium in the skeleton deposits on the cortical and trabecular surfaces of bones and slowly redistributes throughout the volume of mineral bone with time.



**Plutonium metal.** Plutonium isotopes are primarily alpha-emitters so they pose little risk outside the body. Here the plastic bag, gloves, and outer (dead) layer of skin would each alone stop the emitted alpha particles from getting into the body.

**What Is the Primary Health Effect?** Plutonium poses a health hazard only if it is taken into the body because all isotopes but plutonium-241 decay by emitting an alpha particle, and the beta particle emitted by plutonium-241 is of low energy. Minimal gamma radiation is associated with any of these radioactive decays. Inhaling airborne plutonium is the primary concern for all isotopes, and cancer resulting from the ionizing radiation is the health effect of concern. The ingestion hazard associated with common forms of plutonium is much lower than the inhalation hazard because absorption into the body after ingestion is quite low. Laboratory studies with experimental animals have shown that exposure to high levels of plutonium can cause decreased life spans, diseases of the respiratory tract, and cancer. The target tissues in those animals were the lungs and associated lymph nodes, liver, and bones. However, these observations in experimental animals have not been corroborated by epidemiological investigations in humans exposed to lower levels of plutonium.

**What Is the Risk?** Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including plutonium (see box at right). While ingestion is generally the most common route of exposure, the risk coefficients for this route are much lower than those for inhalation. As for other radionuclides, the risk coefficients for tap water are about 80% of those for dietary ingestion. (As a note, the common myth that plutonium is the “deadliest substance known to man” is not supported by the scientific literature. It poses a hazard but is not as immediately harmful to health as many chemicals. For example, for inhalation – the exposure of highest risk – breathing in 5,000 respirable plutonium particles, about 3 microns each, is estimated to increase an individual’s risk of incurring a fatal cancer about 1% above the U.S. average “background” rate for all causes combined.)

### Radiological Risk Coefficients

This table provides selected risk coefficients for inhalation and ingestion. Recommended default absorption types were used for inhalation, and dietary values were used for ingestion. Risks are for lifetime cancer mortality per unit intake (pCi), averaged over all ages and both genders ( $10^{-9}$  is a billionth, and  $10^{-12}$  is a trillionth). Other values, including for morbidity, are also available.

Isotope	Lifetime Cancer Mortality Risk	
	Inhalation ( $\text{pCi}^{-1}$ )	Ingestion ( $\text{pCi}^{-1}$ )
Plutonium-238	$3.0 \times 10^{-8}$	$1.3 \times 10^{-10}$
Plutonium-239	$2.9 \times 10^{-8}$	$1.3 \times 10^{-10}$
Plutonium-240	$2.9 \times 10^{-8}$	$1.3 \times 10^{-10}$
Plutonium-241	$2.8 \times 10^{-10}$	$1.9 \times 10^{-12}$
Plutonium-242	$2.8 \times 10^{-8}$	$1.3 \times 10^{-10}$

For more information, see the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients and accompanying Table 1. Risk coefficients are not available for plutonium-244.